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FORCE TESTS OF LENTICULAR SHAPES IN TUNNEL HOTSHOT 1

By

William Wolny

VKF, ARO, Inc.

April 1960

ARNOLD ENGINEERING DEVELOPMENT CENTER

RESEARCH AND DEVELOPMENT COMMAND

US AF

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ARO Project No. 361044

Contract No. AF 40(600)-800

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ABSTRACT

Force tests of six configurations of two lenticular shapes were conducted in Tunnel Hotshot 1 to determine lift, drag, and pitching moment characteristics at angles of attack from 0 to 10 and 80 to 100 deg. Mach numbers at which the tests were run varied from 16 to 20 and Reynolds number from 45,000 to 118,000 based on root chord. The effectiveness of two control devices on one shape and one control device on the second shape were tested. Data trends and static stability characteristics were established over the angle-of-attack range investigated.

NOMENCLATURE

C_D	Drag coefficient, D/qS
C_L	Lift coefficient, L/qS
C_m	Pitching moment coefficient about cg, m/qS
c	Chord length, maximum diameter
cg	Center of gravity
D	Drag
L	Lift
M	Free-stream Mach number
m	Pitching moment about cg
q	Dynamic pressure, $\rho V^2/2$
Re	Free-stream Reynolds number based on model diameter
r	Radius
S	Model reference area, based on model diameter
t	Maximum model thickness
V	Free-stream velocity
α	Angle of attack
ρ	Free-stream density

INTRODUCTION

A general aerodynamic investigation of lenticular shapes throughout the Mach number range from transonic to Mach number 20 has been conducted for the Air Proving Ground Center (APGC), Eglin Air Force Base, Florida in the Arnold Engineering Development Center (AEDC) wind tunnels. This report covers tests in Tunnel Hotshot 1 of the von Karman Gas Dynamics Facility (VKF), on six lenticular configurations from January 4 to January 15, 1960.

Three component force data were obtained at angles of attack from 0 to 10 and 80 to 100 deg for free-stream Mach numbers from 16 to 20 and Reynolds numbers (based on root chord) from 45,000 to 118,000.

APPARATUS

WIND TUNNEL

Tunnel Hotshot 1 (Fig. 1) is a hypervelocity, blow-down type wind tunnel with a 16-inch diameter test section. It is currently capable of producing free stream velocities of 10,000 ft/sec, Mach numbers from 16 to 22, and densities equivalent to altitudes between 150,000 and 200,000 feet. In a Hotshot tunnel a relatively small mass of air, confined in the arc chamber, is heated and pressurized by discharging into it stored electrical energy. This air is then allowed to expand through a conical nozzle and into the test section where the desired hypervelocity flow is obtained for approximately 30 milliseconds.*

MODELS

The APGC supplied resin-impregnated fiberglass models of six lenticular configurations (Figs. 2, 3, 4, 5, and 6). Models 10C, 11C, 7/10C, and 6/10C were of hollow shell type construction with a 0.02-in. thick skin and an access hole for internally mounting the force balance along the chord axis. Models 1CA and 7CA were 0.06-in. thick and were screwed onto a mounting bracket which fitted onto the force balance. Photographs of Models 1CA and 7/10C mounted in the tunnel

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*Test Facilities Handbook, (2nd Edition). "Gas Dynamics Facility, Vol. 4." Arnold Engineering Development Center, January 1959.

Manuscript released by author March 1960.

are presented in Figs. 7 and 8. A shroud, provided to cover the balance and the Model 1CA mounting bracket, has been removed in this photograph (Fig. 7).

Models 7/10C and 6/10C were identical to Model 10C except for the addition of control devices (booms, tabs, and flaps). Model 11C was identical to Model 10C except for the blunt edge. These models had a t/c = 0.226 with the exception of Model 11C which had a t/c = 0.234 because of its blunt edge. Models 1CA and 7CA had a t/c = 0.138 and were identical except for stabilizing booms on Model 7CA.

INSTRUMENTATION

Signals from the various types of transducers were fed into a 20 kilocycle carrier amplifier and recorded in analog form on high speed oscillographs.

Pressure

Arc chamber pressures were measured with a strain-gage type transducer. Tunnel nozzle pressures and the test section pitot pressure were measured with variable reluctance transducers.

Force

Model forces were measured with three-component, internal, full-bridge, strain-gage balances developed at the AEDC. The axial force was measured along the balance centerline which coincided with the model centerline. The normal forces were measured in two positions from which total normal force and pitching moment were determined. The rapid time response required in Hotshot tunnels was obtained by using lightweight models and high frequency strain members in the balance.

Optical

High speed motion pictures and still photographs were taken of the luminous flow over the model for all runs. The motion pictures permitted analysis of flow stability over the model and clearly indicated flow separations.

A 10-in.-diam single pass schlieren system permitted the visualization of shock patterns about the model. An intense spark light source and a 0.6 microsecond Faraday shutter were used to subdue luminosity of the flow over the model. An example of the schlieren photographs taken during the steady portion of flow is shown in Fig. 9.

PROCEDURE

Tests were conducted at angles of attack of 80, 85, and 90 degrees for the symmetrical Model 1CA and in five degree increments from 80 to 100 degrees for Model 7CA. The remainder of the configurations were tested at angles of attack from 0 to 10 degrees.

The tunnel was operated to produce a Mach number near 20 without blockage. The Mach number-Reynolds number envelope and the velocity-density altitude range covered in the tests are shown in Figs. 10 and 11.

Tunnel reservoir and free-stream conditions were calculated at regular time intervals for each run. The computations, made by an electronic computer, were based on an isentropic expansion using empirical equations of state for air.

During a typical run, the starting transient occupied the first several milliseconds of the run followed by 20 to 30 milliseconds of quasi-steady flow prior to flow breakdown or separation of the flow over the model. During the quasi-steady flow, force and pressure measurements decreased with time because of the pressure and density decay in the reservoir. This systematic variation of the force data was eliminated by nondimensionalizing into coefficient form.

Precision of data is represented as the maximum variation of coefficients from the faired curves. Values for Models 1CA and 7CA are $C_L = \pm 0.015$, $C_D = \pm 0.10$ and $C_m = \pm 0.02$, and for the remaining models, $C_L = \pm 0.026$, $C_D = \pm 0.020$ and $C_m = \pm 0.0065$.

RESULTS AND DISCUSSION

Trends of lift coefficient with angle of attack, drag coefficient with lift coefficient, and pitching moment coefficient with lift coefficient were obtained for all the models and are shown in Figs. 12 through 15.

Figure 12 indicated longitudinal stability characteristics for models 1CA and 7CA. The lift curve for each model indicates a negative $(dC_L/D\alpha)$. Because differences in drag are not apparent, a single drag polar is presented. Models 1CA and 7CA were stable about $\alpha = 90°$ and $\alpha = 80°$, respectively.

The longitudinal stability characteristics for Models 10C and 11C are shown in Fig. 13. It is evident that the model dissimilarity (blunt leading edge) was insufficient to produce measurable differences. Both models were unstable over the range tested. Static margin of stability was approximately -20 percent of root chord for both models.

Static stability characteristics for Model 7/10C are shown in Fig. 14. The addition of the booms to the basic model resulted in negligible change in lift; however, drag was increased over that of the basic shape. The booms increased stability, but not enough to make the configuration stable. Static margin was approximately -2 percent of root chord. Characteristics for Model 6/10C are shown in Fig. 15; the lift curve slope and drag were greater than that of the basic shape (Fig. 13). This model exhibited neutral stability at angles of attack between 0 and 5 degrees.

CONCLUSION

Booms and flaps decreased model instability at small angles of attack, but not to the extent of making the models stable. This conclusion applies to the models over the range of variables tested.

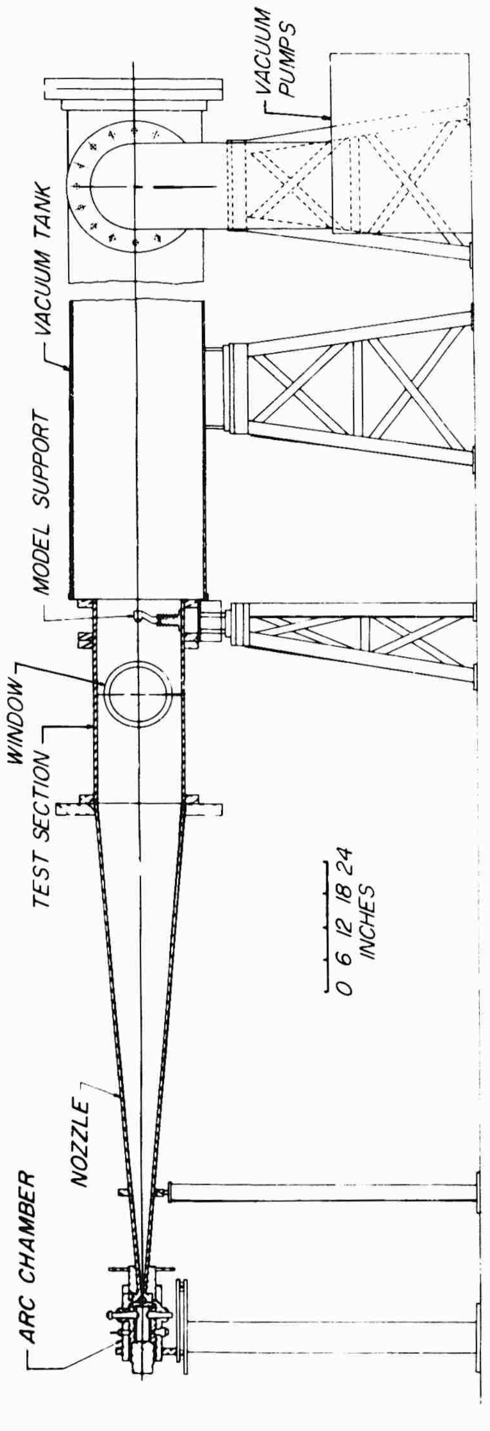
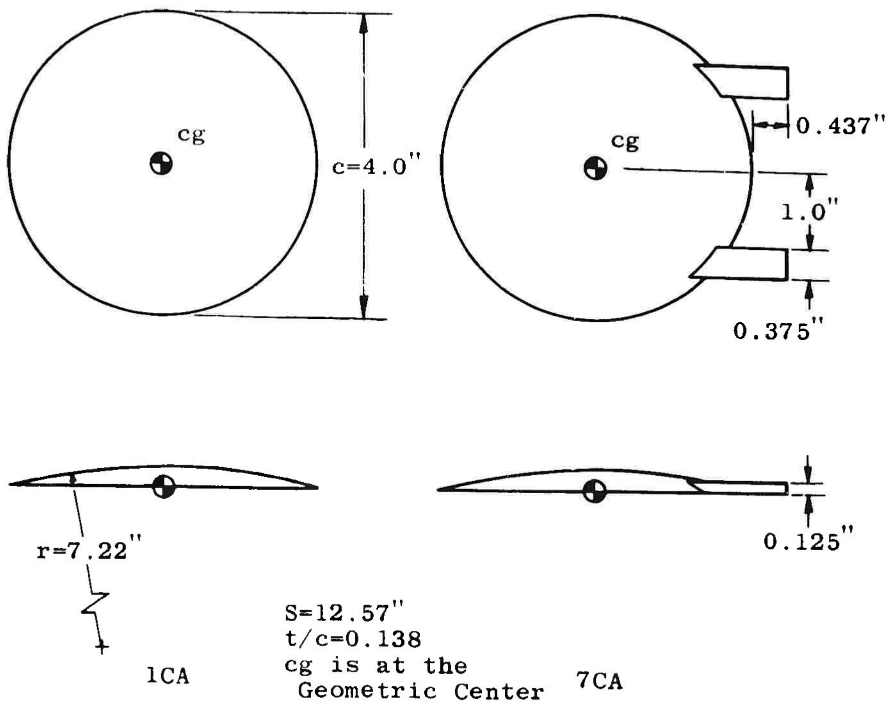


Fig. 1 Tunnel Hotshot 1, a 16-in.-diam Hypervelocity Wind Tunnel



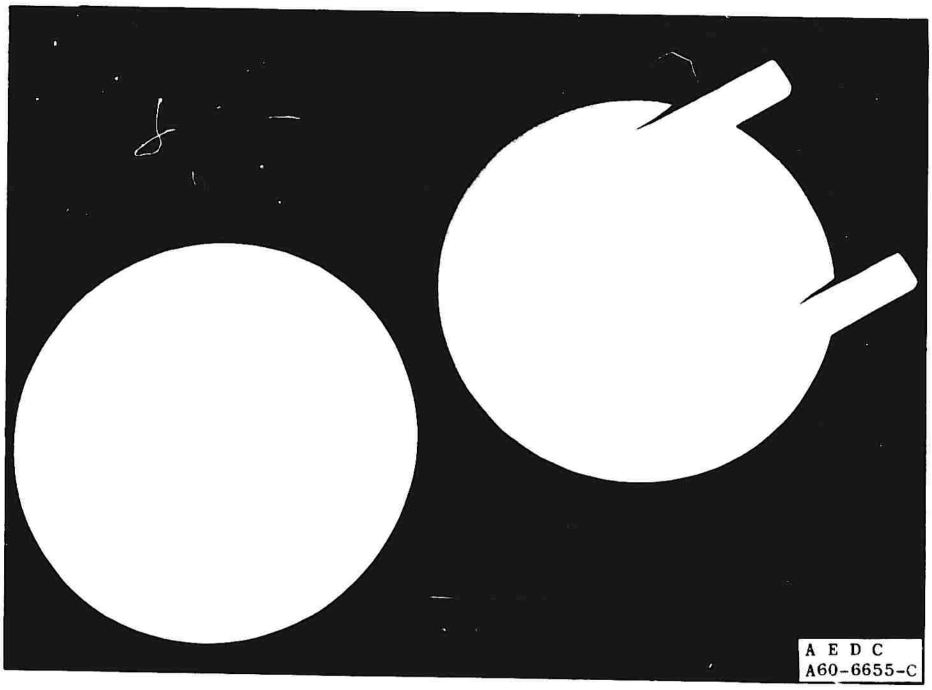


Fig. 2 Models 1CA and 7CA

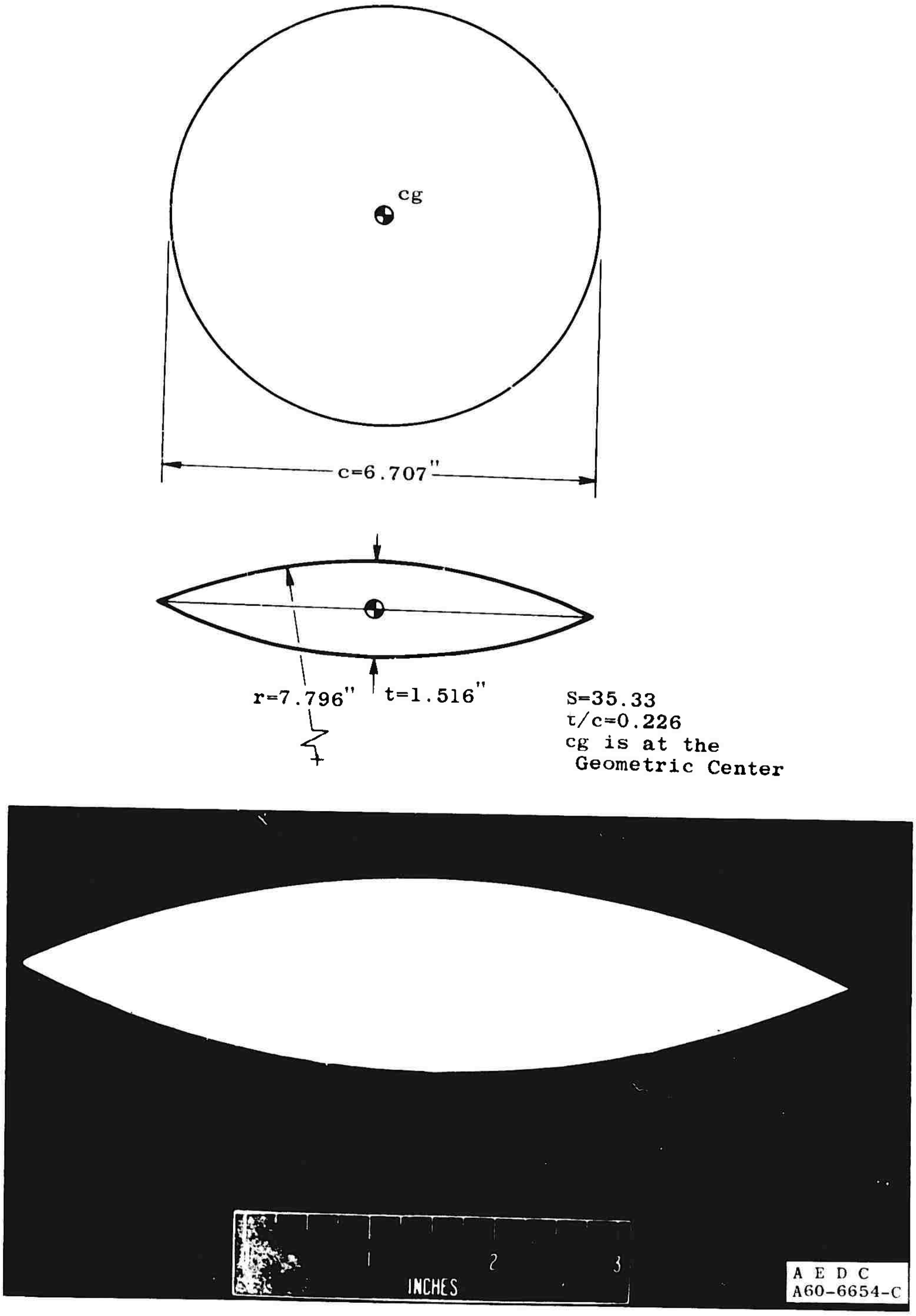
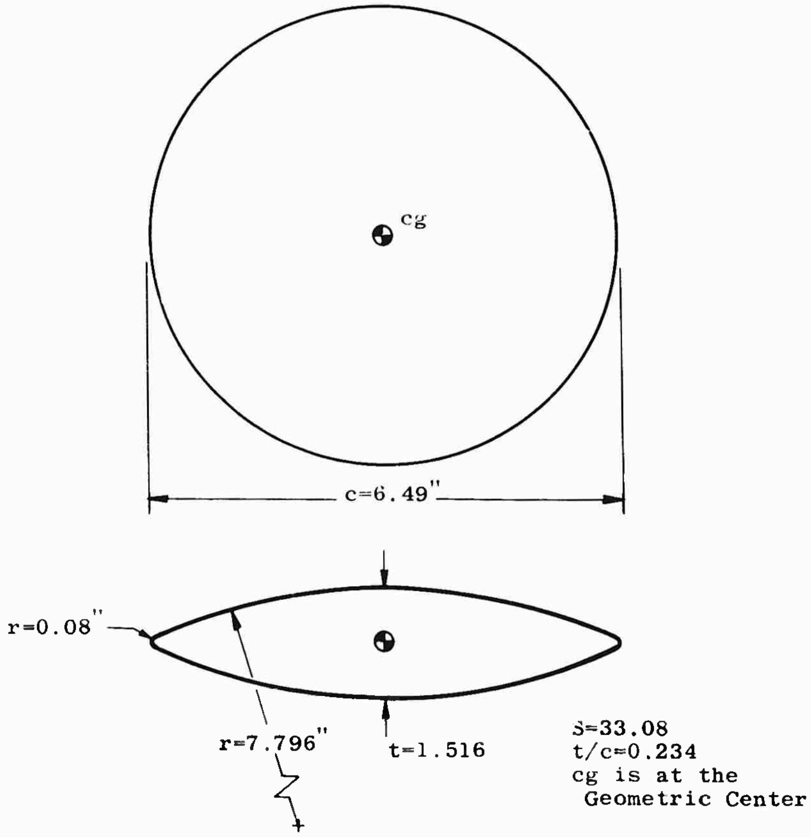


Fig. 3 Model 10C



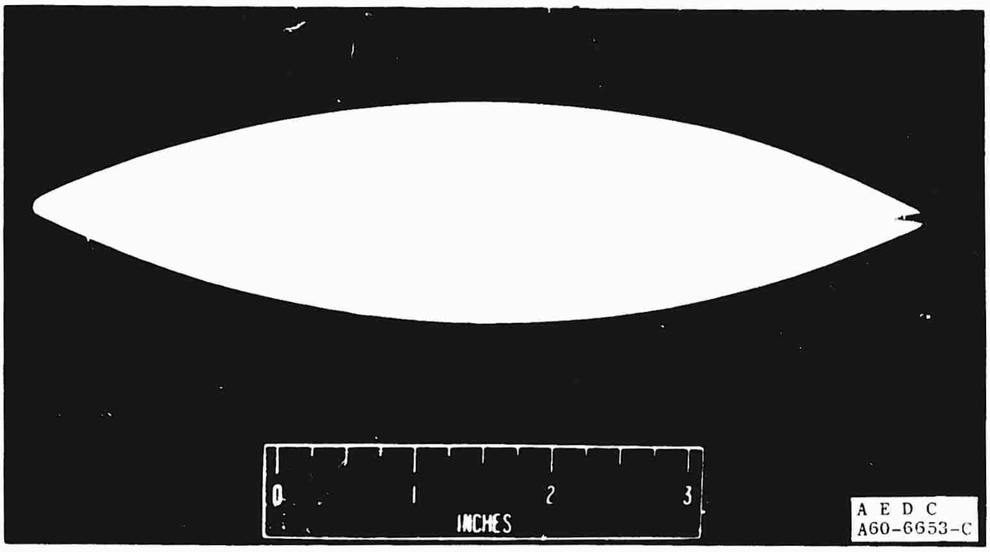


Fig. 4 Model 11C

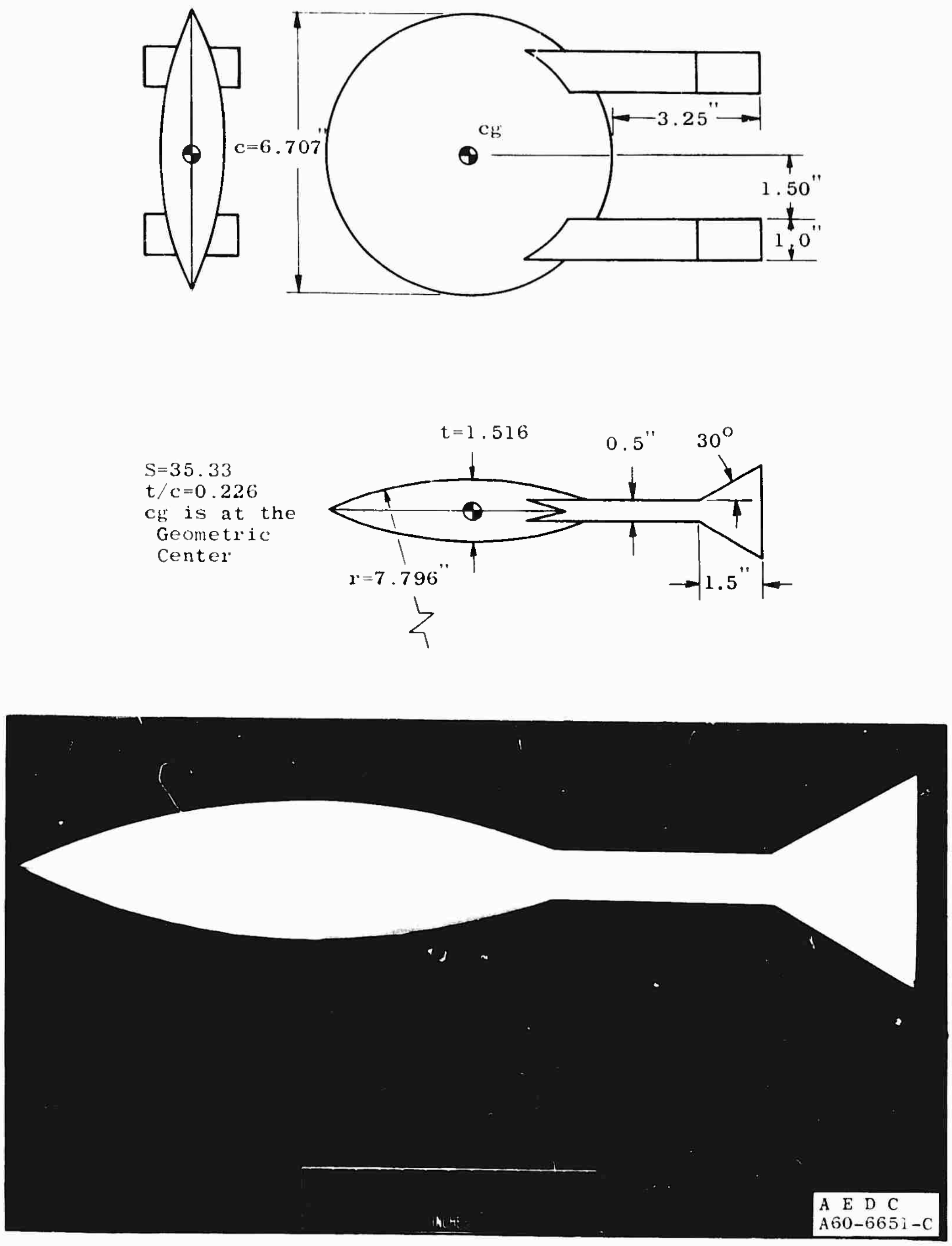
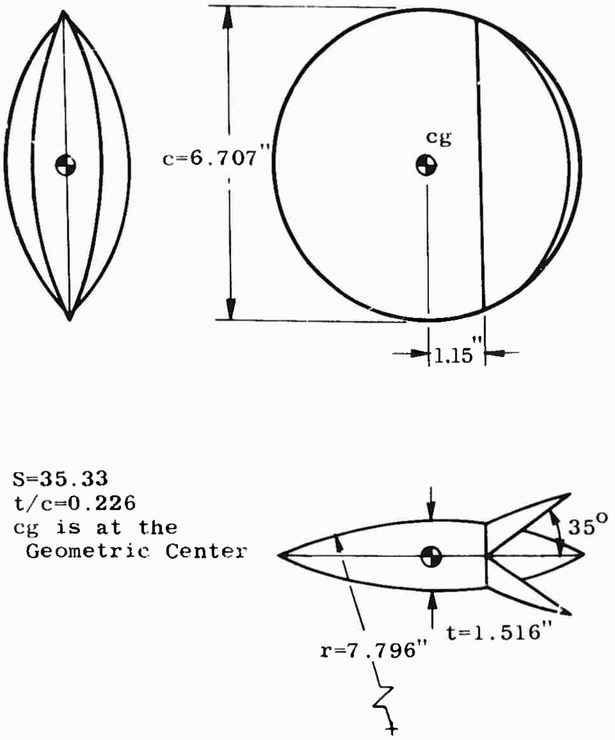


Fig. 5 Model 7/10C



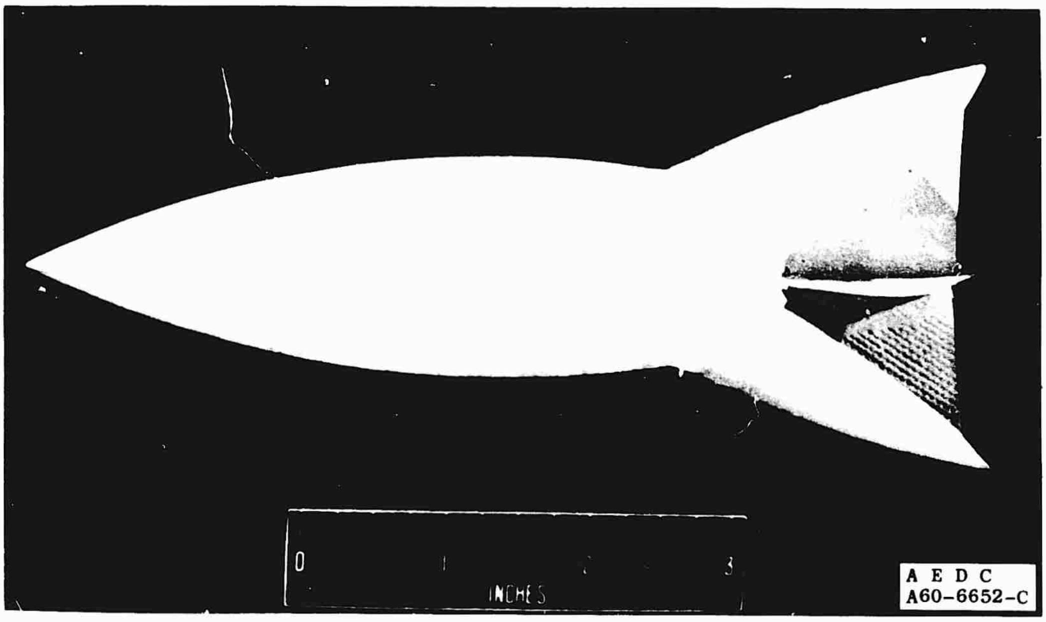


Fig. 6 Model 6/10C

Fig. 7 Model 1CA Mounted in Test Section

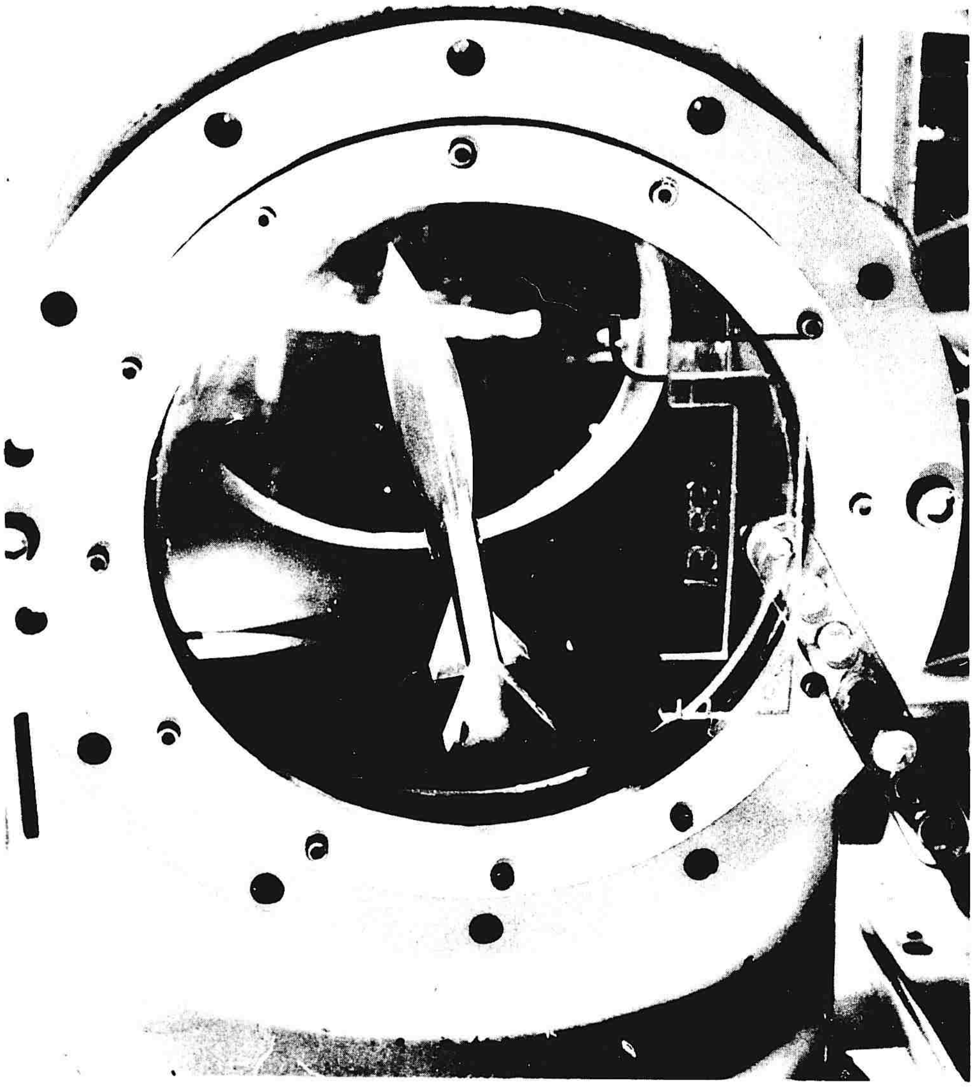


Fig. 8 Model 7/10C Mounted in Test Section

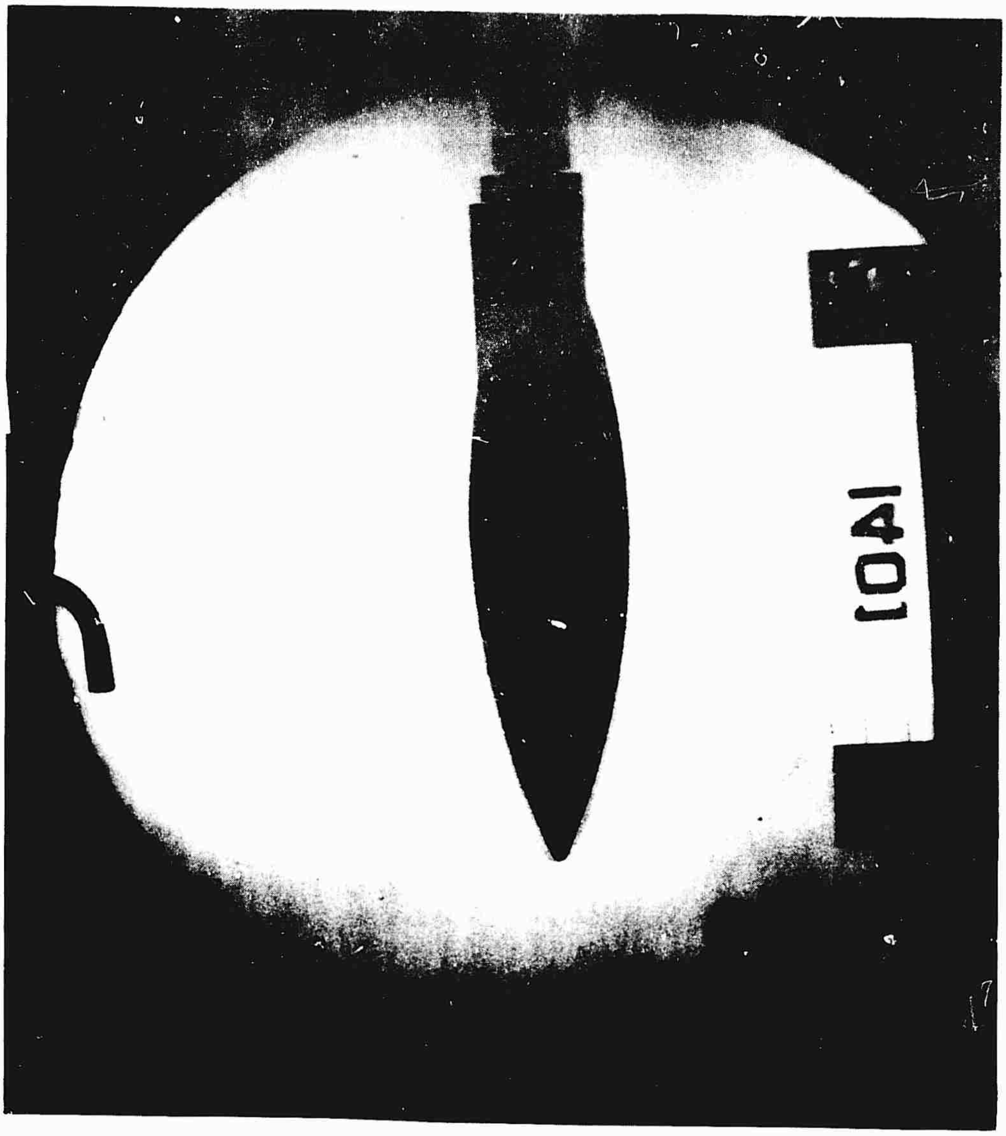


Fig. 9 Schlieren Photograph of Model 11C, $\alpha = 0°$, $M = 16.05$, $Re = 96 \times 10^3$, $V = 10^4$ ft/sec

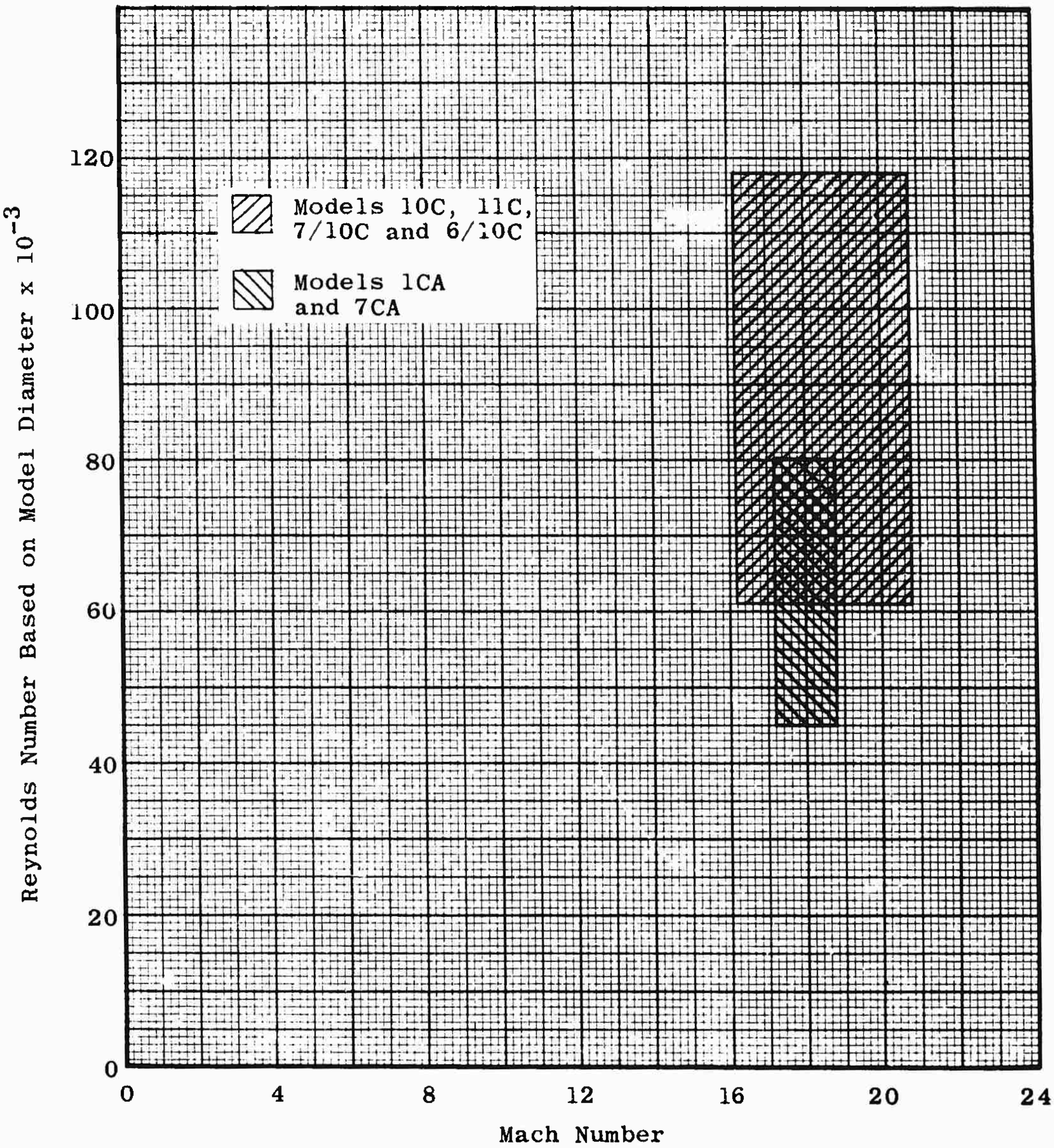


Fig. 10 Reynolds Number and Mach Number Range

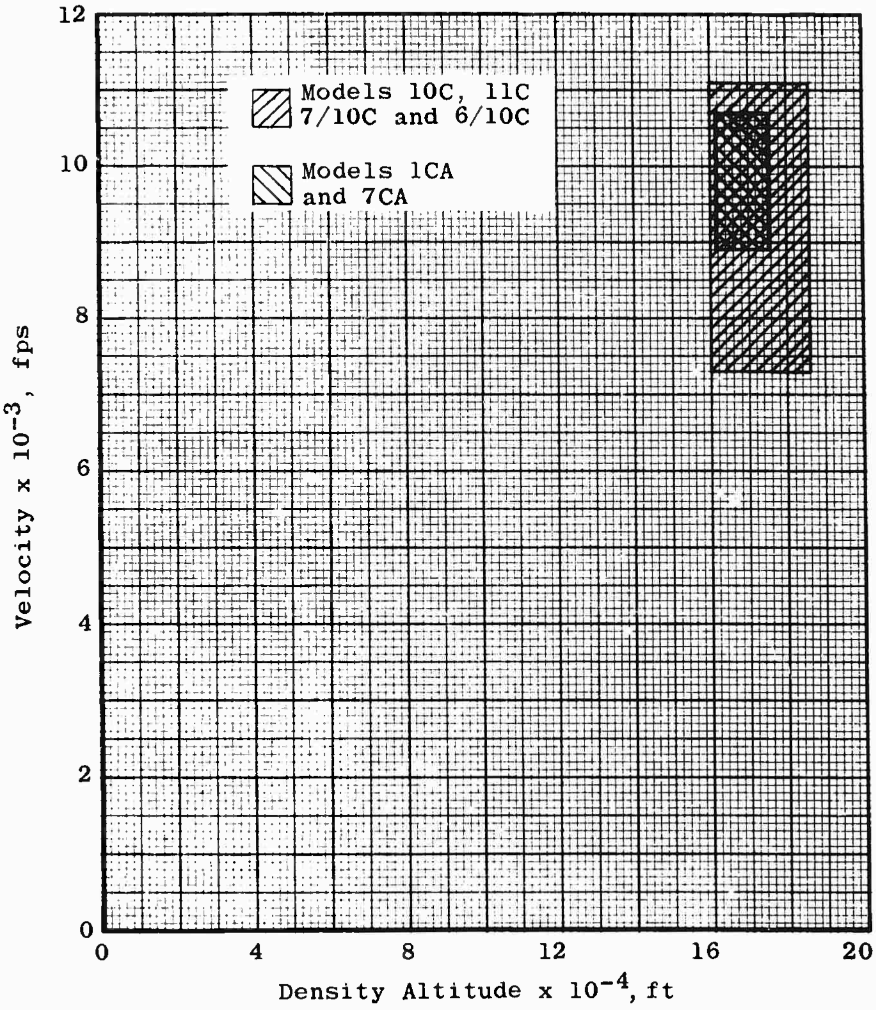


Fig. 11 Velocity and Density Altitude Range

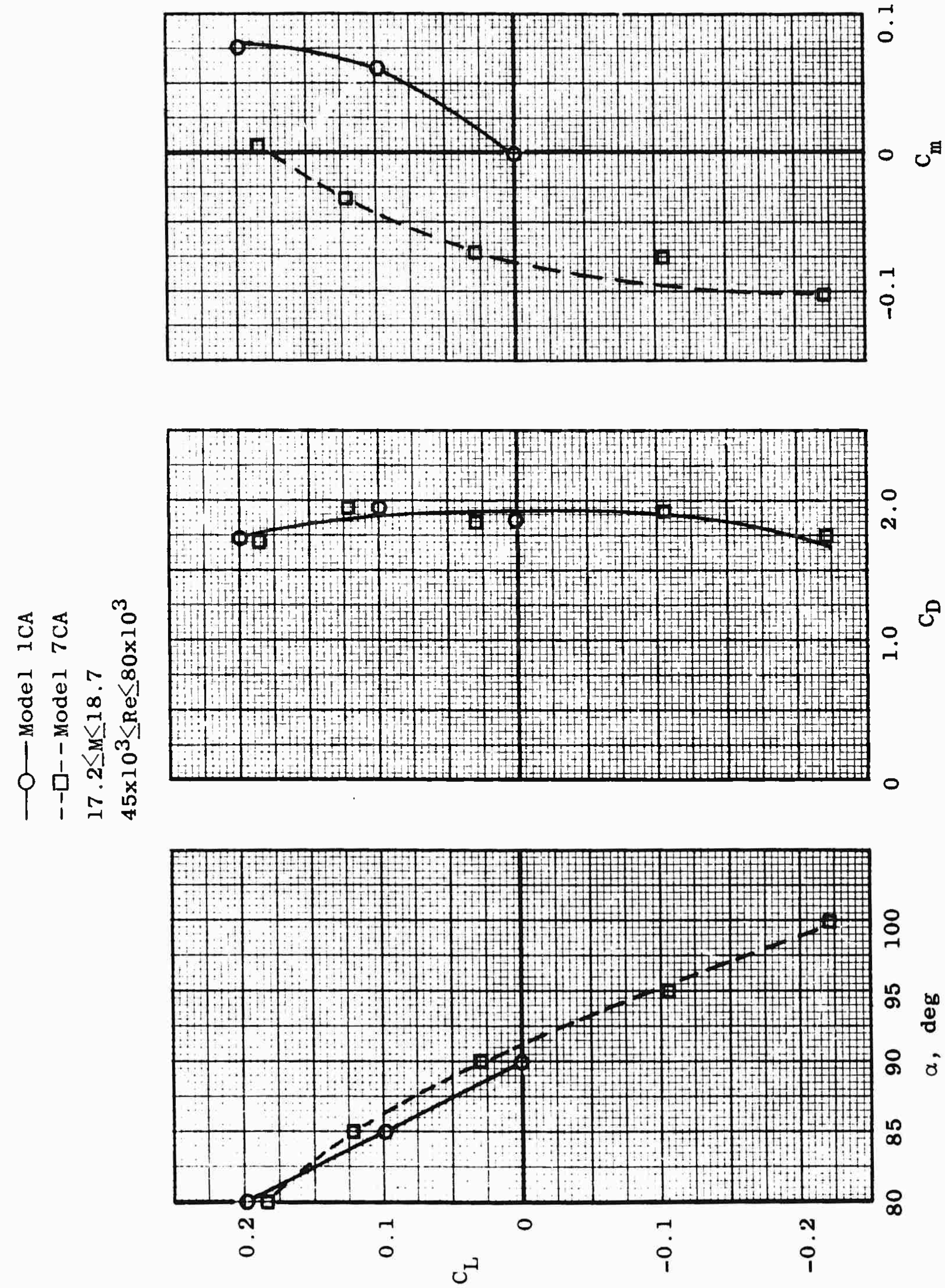


Fig. 12 Force and Moment Coefficients for Models 1CA and 7CA

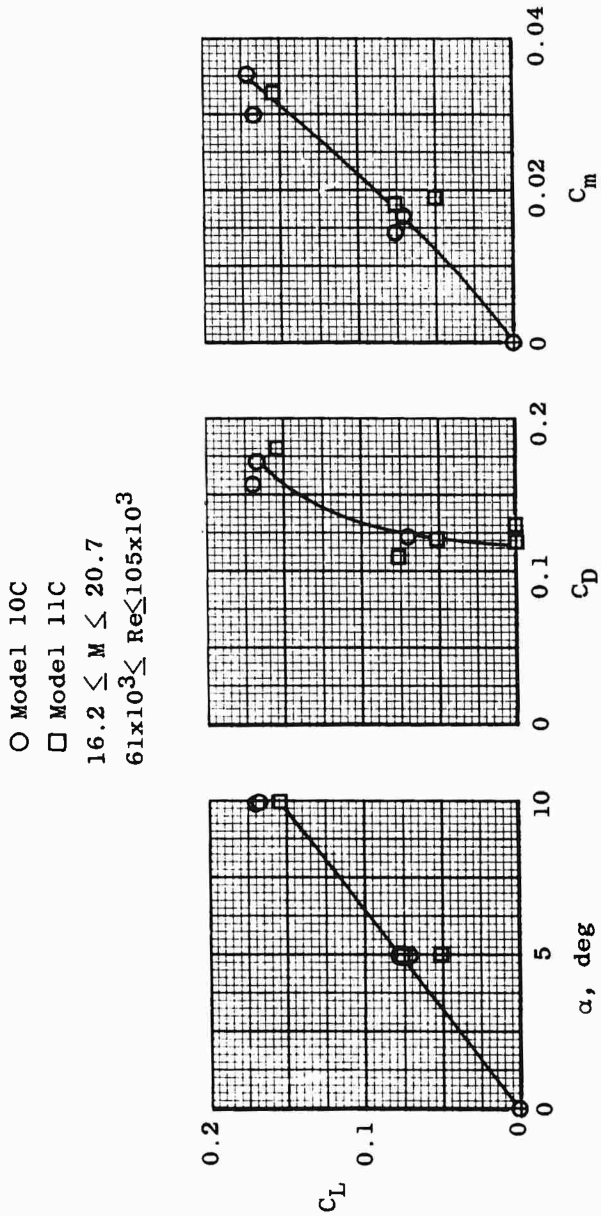


Fig. 13 Force and Moment Coefficients for Models 10C and 11C

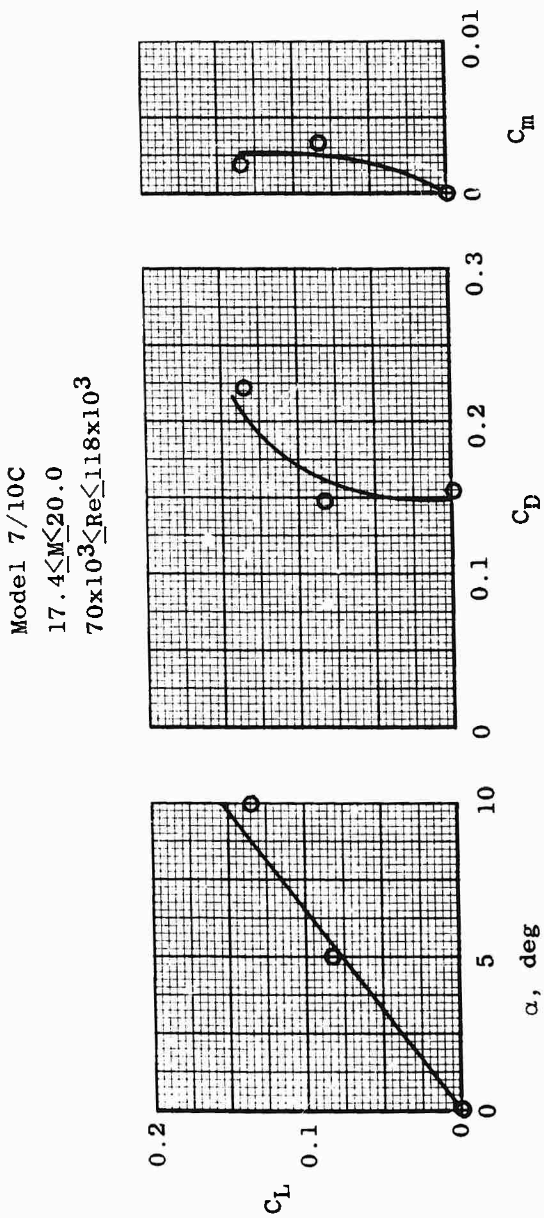


Fig. 14 Force and Moment Coefficients for Model 7/10C

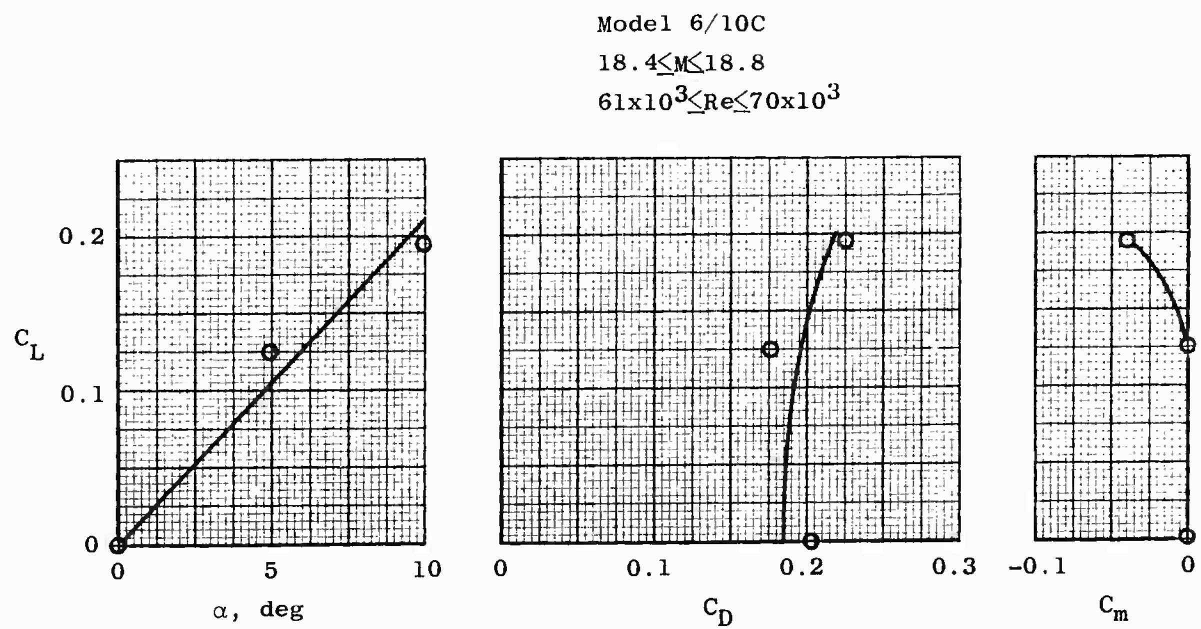


Fig. 15 Force and Moment Coefficients for Model 6/10C